

BMP Planning to Address Urban Runoff Glen Flora Tributary, Lake County *SUSTAIN* Pilot

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1. Introduction

There are few remaining watersheds draining to Lake Michigan within Illinois. Activities within these watersheds have the potential to directly affect the Lake as well as nearshore habitats and water quality. The Glen Flora Tributary watershed, located in the larger Dead River watershed, was identified early in the project as a suitable pilot watershed. The pilot watershed is approximately 1,000 acres in size and located in Lake County, Illinois as is tributary to Lake Michigan.

The proposed purpose and goals of the *SUSTAIN* application within Lake County is to provide technical support for local planning and implementation of BMPs to improve water quality and mitigate flood damage by:

- Providing a summary of cost-effective BMPs that will help address flooding and water quality concerns.
- Evaluating the effectiveness of regional versus site scale BMPs to mitigate localized flooding.
- Providing a template for focused stormwater retrofitting.
- Utilizing an existing PCSWMM model as input to *SUSTAIN* to evaluate design storm hydrology and hydraulics.
- Demonstrating the use of *SUSTAIN* and BMPDSS to address different elements of the study.

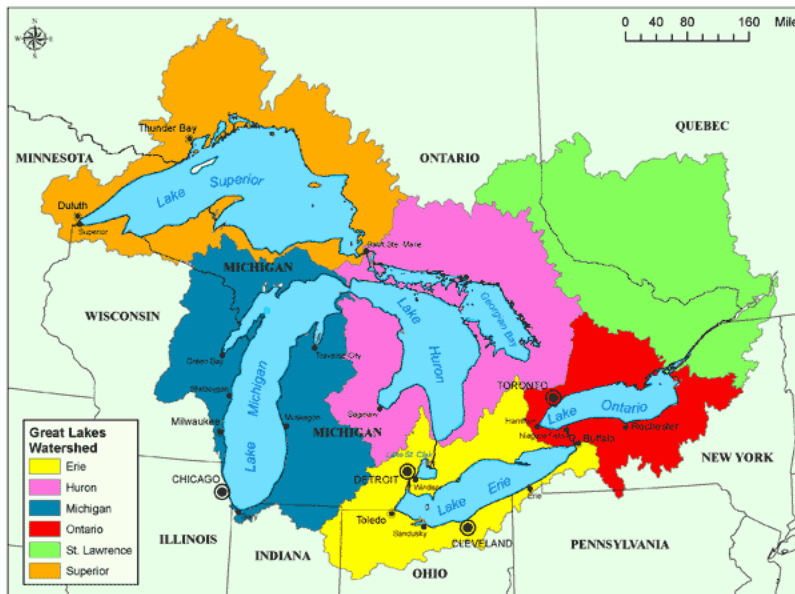


Figure 1-1. Great Lakes watershed (courtesy of Ohio DNR)

An overall watershed management plan was developed for the Dead River Watershed by the Lake County Stormwater Management Commission in 2008. This Plan sets forth a series of goals for the watershed which include the following related to water quality pollutant reductions and stormwater:

- Total suspended solids (75 percent reduction)
- Low dissolved oxygen (50 percent reduction)
- Nutrients (50 percent reduction)
- Rate and volume of runoff (75 percent reduction)

The watershed plan recommended a set of implementation actions which included using green infrastructure and stormwater BMPs to address stormwater and water quality. Specific recommendations were not included on the size, quantity, or placement of suggested BMPs.

Flooding within the Lake County Gardens Subdivision, located wholly within the proposed pilot area, was evaluated as part of a study conducted between 2003 and 2006. The following flood related issues were identified:

- Flooding of basements due to sanitary sewer backups

- Ponding in streets and backyards
- Overbank flooding from the North Shore Ditch

Finally, a series of hydrologic and hydraulic modeling studies have been completed for the Glen Flora Tributary and its watershed including the most recent work by the U.S. Army Corps of Engineers (ACOE) for the Zion Beach-Ridge Plain Restoration Project, currently underway. This project included the development of a watershed model which was used to provide detailed input to BMP optimization models used as part of this pilot project.

2. Pilot Area Selection

The Glen Flora Tributary watershed (Figure 2-1) was selected as the *SUSTAIN* pilot area after discussions with stakeholders regarding possible locations. The key factors that were considered during pilot area selection were: representativeness of the area to other locations, data availability, previous work conducted, watershed size, potential project objectives, and local support. The Lake County Stormwater Management Commission recommended the portion of the watershed upstream of Sheridan Road for the pilot area (Figure 2-2).

The Glen Flora Tributary watershed consists of predominantly single-family residential. In addition to homes, the watershed includes a golf course, shopping centers, several parks, medium density apartments, many schools, and significant protected natural areas. The portion of the watershed downstream of Sheridan Road consists of wetlands, ponds, and a large impervious area. Land cover in the watershed is mostly developed urban area, including open spaces which includes lawn areas and the golf course, accounting for 82 percent of the total area (Table 2-1 and Figure 2-2). Natural surfaces cover the remaining 18 percent, which is primarily forested and wetlands.

Table 2-1. 2006 land cover distribution

Land Cover	Acres	Percent
Developed, Open Space	233	23%
Developed, Low Intensity	344	34%
Developed, Medium Intensity	223	22%
Developed, High Intensity	35	3%
Forest	125	13%
Shrub	1	< 1%
Grassland	7	1%
Woody Wetlands	10	1%
Emergent Herbaceous Wetlands	22	2%
Total	1,000	

Source: 2006 National Land Cover Database

The Glen Flora Tributary upstream of Sheridan Road is described in the watershed plan:

Upstream of Sheridan Road, the stream flows for approximately 3,000 feet through the Glen Flora Country Club and three ponds, which are created by dams across the stream. The stream and pond edges are armored with rip-rap in some locations and planted to the edge with turf grass in other locations. While the rip rap may help reduce erosion of the stream and pond edges, rip rap and turf grass do little to improve water quality in the stream or improve the stream habitat for aquatic plants and animals. Upstream of the Glen Flora County Club, the Glen Flora Tributary enters a culvert at Poplar and emerges west of the McClory Bike Path where it has been channelized for the rest of its upstream reaches until it disappears into an undefined channel near Lewis Avenue.

There is low to no stream bank erosion identified along the stream. High priority watershed pollutants include: low dissolved oxygen, total suspended solids/sedimentation, nutrients (phosphorus), aquatic life toxicity, and pathogens. Habitat and wetland degradation, invasive species, lack of stream buffers and riparian zones and flood flows and damages were also noted in the watershed assessment.

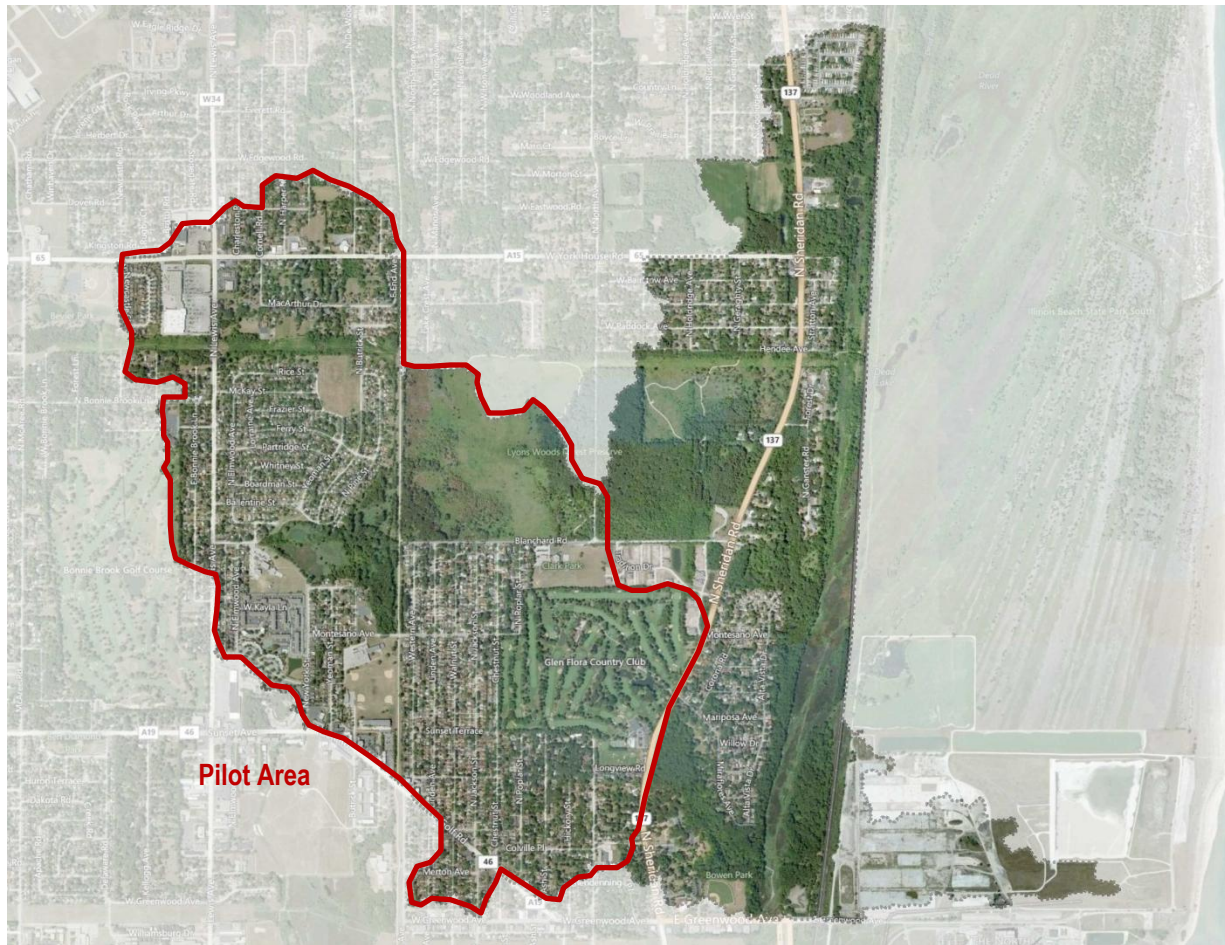


Figure 2-1. Glen Flora Tributary watershed and pilot area.

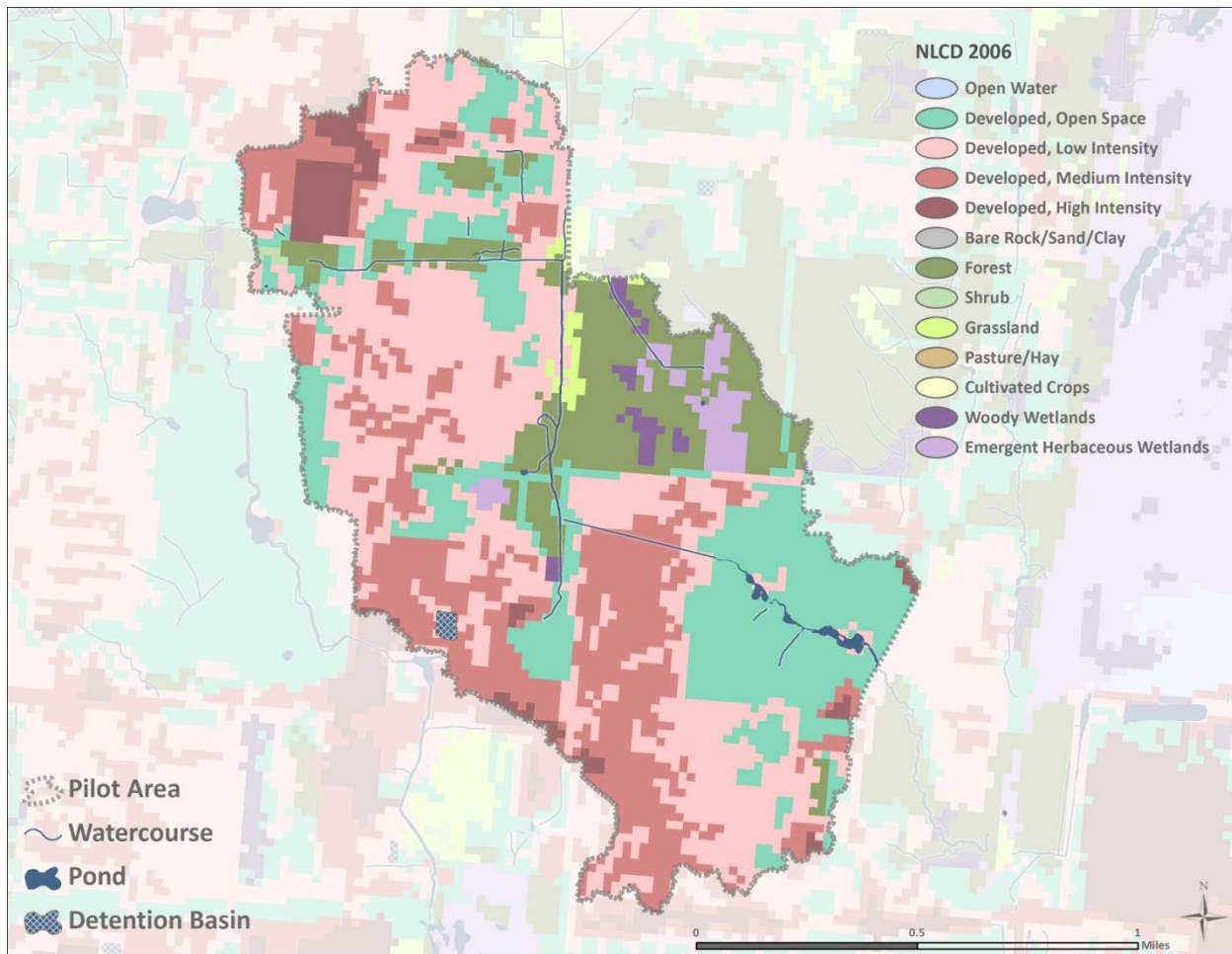


Figure 2-2. Land cover in the Glen Flora Tributary watershed.

Soils within the Glen Flora Tributary watershed are classified by Hydrologic Soil Groups (HSG), which describe the capability of soils to infiltrate water (Figure 2-3). This is of particular importance to BMP modeling, as soils that exhibit better drainage properties will be more useful for infiltrating stormwater. Generally speaking, HSG A soils are sandy or loamy and have a high capacity for water infiltration, while HSG D soils have high clay content or are heavily impacted and tend to sheet water off or pond water at the surface. HSG C soils classification are found throughout the watershed, while HSG D group soils dominate the west-central section near the residential developments, and HSG B type soils exist primarily east of Sheridan Road. The seasonally high water table is less than 32 inches below the surface throughout the watershed (Figure 2-4). In some areas, the water table can be found very near the surface.

Topography in the Glen Flora Tributary watershed grades very gently (approximately 0.67 percent) from west to east. The central section, near the golf course, has a slight ridge, and a relatively steep drop occurs east of Sheridan road as the landscape transitions into lakeshore dunes.

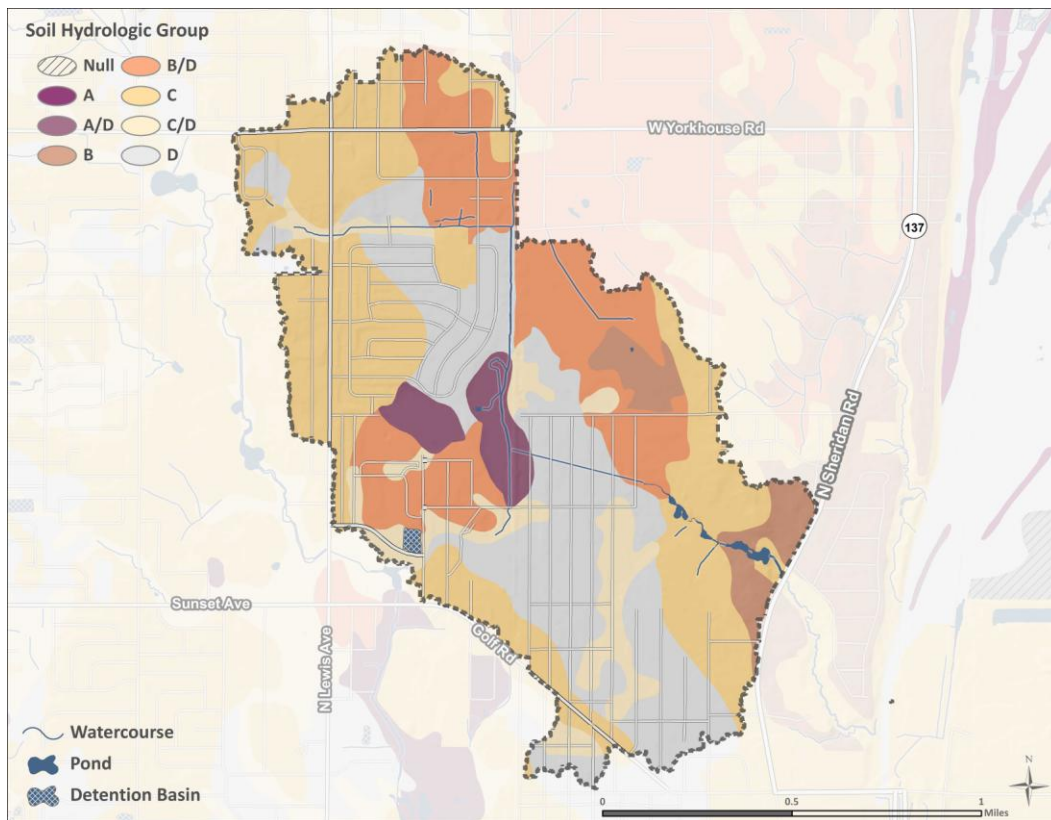


Figure 2-3. Distribution of soils according to HSG.

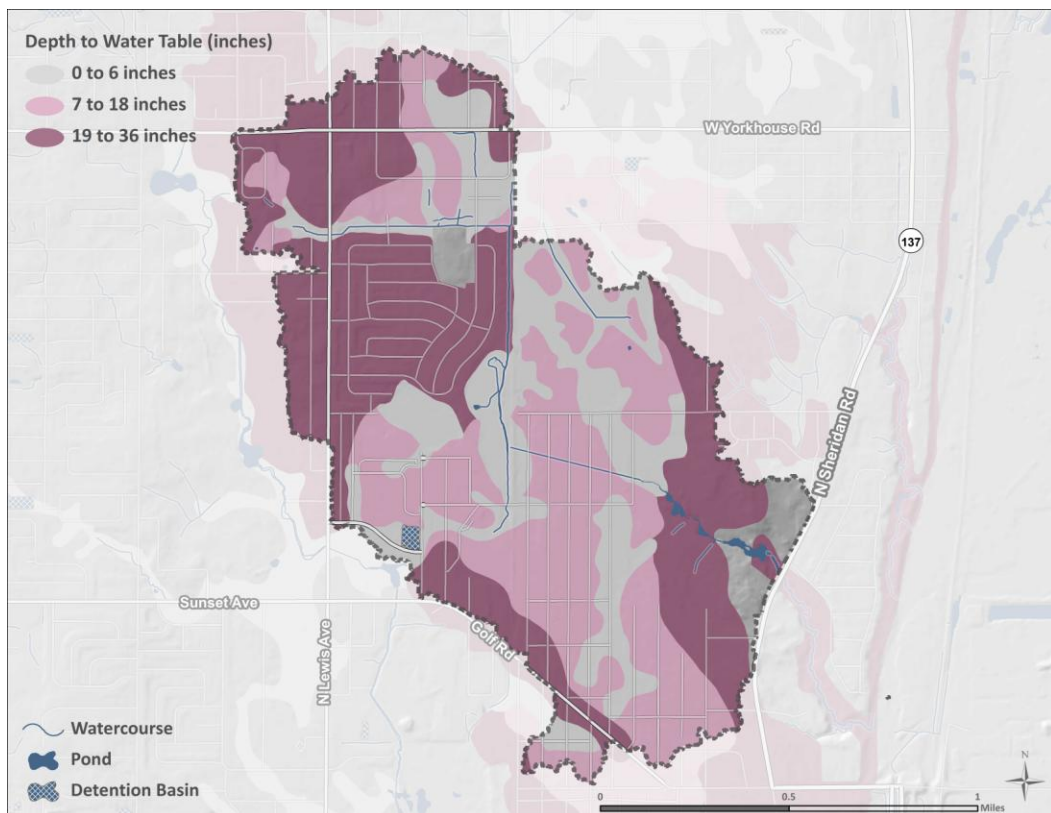


Figure 2-4. Depth to water table.

3. BMP Optimization Approach

Development of effective stormwater management strategies is an important part of the transition from planning to implementation. The goal of this project is to provide technical support for local planning and implementation by analyzing and selecting the most appropriate suite of BMPs to achieve peak flow reductions and associated pollutant load reductions.

Five general steps were used in this pilot effort to evaluate stormwater management opportunities:

- Step 1 - Establish baseline conditions
- Step 2 - Identify potential BMPs
- Step 3 - Determine BMP configurations and performance
- Step 4 - Identify BMP costs
- Step 5 - Perform BMP optimization analysis

Figure 3-1 presents a general flow diagram of the process and identifies considerations and inputs. Information on BMP effectiveness coupled with cost information was used to identify the most economical alternatives through an optimization step. The goal is to target specific implementation activities that address flooding problems related to stormwater. The remainder of this section presents summaries of each of the five analysis steps presented in Figure 3-1.

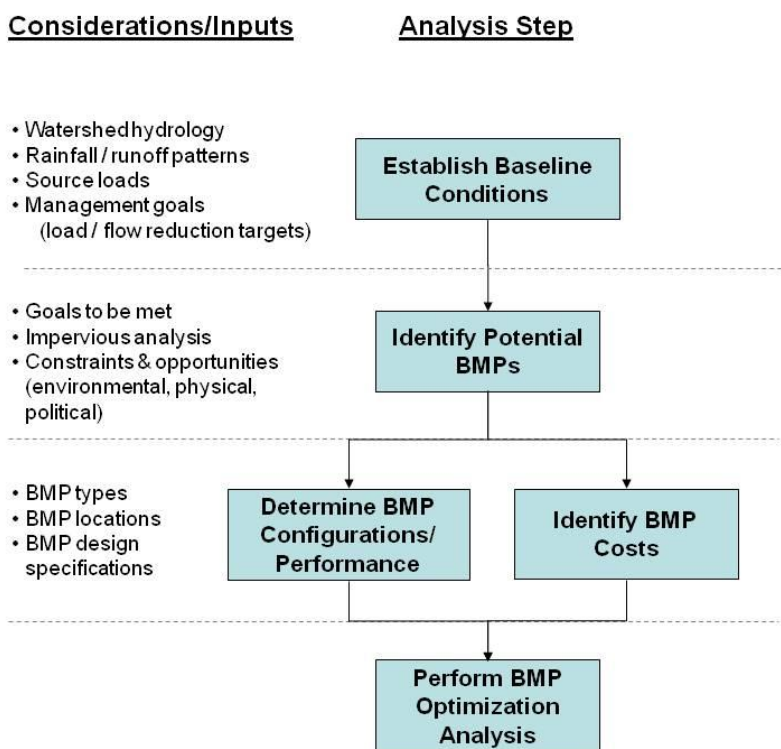


Figure 3-1. Process for BMP targeting and optimization.

Step 1 – Establish Baseline Conditions. The initial step in evaluating and selecting BMPs to achieve stormwater management program goals is to establish baseline conditions. Baseline conditions reflect the existing flow conditions and pollutant loading, as applicable, from a stormwater source. Identifying and

understanding baseline conditions provides a starting point from which improvements are made and progress is measured (i.e., BMP effectiveness is measured against the established baseline conditions).

Step 2 – Identify Potential BMPs. In the second step, baseline condition information is coupled with local factors to generate a list of potential BMPs. Information about baseline conditions provides a benchmark that helps stormwater planners identify potential BMPs, or combinations of BMPs, to achieve overall program goals. In its simplest form, for example, the runoff volume produced by a certain design storm can be used to estimate detention needs. While identifying and selecting potential BMPs, it is important to understand other factors that might affect successful BMP implementation. These factors include environmental, physical, social, and political considerations.

Step 3 – Determine BMP Configurations and Performance. The goal of this step is to evaluate the list of potential BMPs and determine their overall performance at the watershed-scale. The intent is to identify options prior to selecting final BMP strategies. Assessing configuration opportunities, stormwater planners can examine the expected performance of potential BMPs to help select those that will meet the goals identified in Step 1. Although challenging, this activity is essential to selecting BMPs with the most potential for making progress toward management objectives. For purposes of describing the overall process, this is discussed as a separate step after compiling the list of possible BMPs. However, stormwater planners can make assumptions and determinations about BMP configuration and performance while generating the list.

Step 4 – Identify BMP Costs. Identifying BMP costs is an important undertaking for stormwater planners. Resource constraints can affect the number and type of BMPs that can be used to achieve progress toward program goals. At a minimum, stormwater planners should compare costs and expected reductions to ensure the final suite of BMPs will provide the most reductions for the least amount of money. For stormwater planners engaged in a more rigorous BMP optimization analysis, cost information on potential BMPs is essential for developing cost-effectiveness ratios (i.e., cost per unit of pollutant removed) to compare different BMPs for one type of land use or across several types of land uses.

Step 5 – Perform BMP Optimization Analysis. At this stage, stormwater planners have identified the suite of feasible BMPs based on site-specific needs, goals, opportunities and constraints. Depending on the size of the planning area, the implementation goals and the resources available, there could be any number of combinations of BMP types and locations to meet goals. A goal of targeting and optimization is to examine management strategies based on opportunities consistent with site suitability considerations. For example, slope and soil infiltration rates are key factors that affect successful performance of structural BMPs.

To select the final BMP strategy, stormwater planners generally evaluate, prioritize or rank the potential BMPs based on relevant decision criteria, either qualitatively or quantitatively. Decision criteria may include short-term and long-term costs, BMP performance, expected progress toward watershed goals, and compatibility with other planning priorities and objectives. Depending on the area and number of BMPs needed, a stormwater planner might use a qualitative evaluation of potential BMPs and targeted locations based on professional and local knowledge. Simple spreadsheet analysis could also be employed to identify the most appropriate and cost-effective scenario. While adaptive management can support the short-term implementation of priority BMPs with subsequent evaluation and modification, a stormwater planner tries to identify the most effective scenario first to minimize the need for additional BMPs and associated implementation costs. Therefore, the level of detail for the evaluation to select final BMPs can be driven by the benefit of the additional analyses compared to the potential costs to correct ineffective implementation.

4. Establish Baseline Conditions

Effective implementation planning starts with a review of baseline conditions and watershed-scale factors that contribute to documented water-related problems. An understanding of the basic hydrology of the watershed is necessary to establish baseline conditions.

The water cycle is a natural, continuous process that can be generalized as the movement of rainfall from the atmosphere to the land, then back to the atmosphere. The balanced water cycle of precipitation, evapotranspiration, infiltration, groundwater recharge, and stream base flow is a key part of sustaining fragile water resources (Figure 4-1). When identifying and establishing baseline conditions, a critical part of the analysis involves an assessment of rainfall patterns and watershed characteristics that affect the resultant runoff. Source areas and delivery mechanisms that will be the focus of targeted BMPs are driven by watershed response to precipitation. Describing the frequency and magnitude of rain events in conjunction with an analysis of associated runoff are key considerations in establishing baseline conditions and for eventually determining appropriate stormwater management strategies.

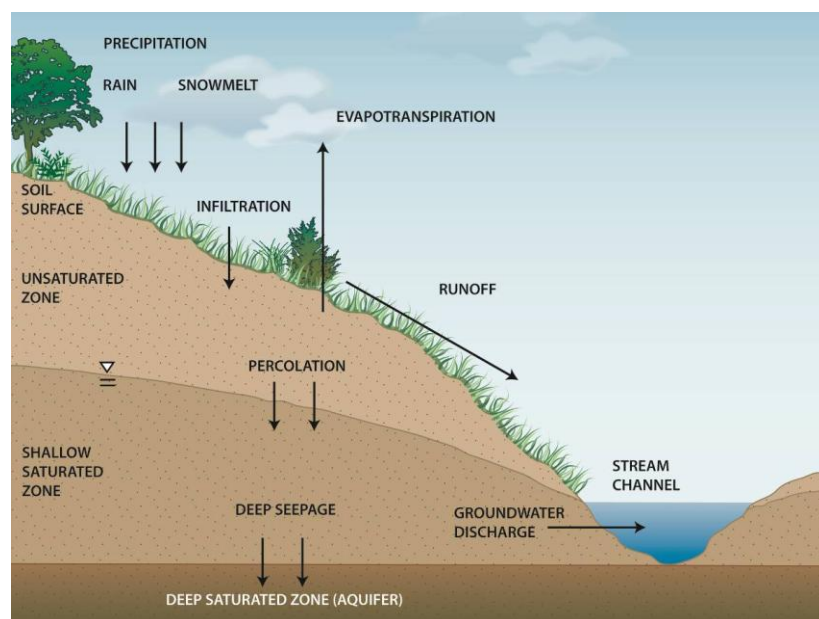


Figure 4-1. Simplified representation of the elements in the water cycle.

4.1.1 Design Storms

Considering the major objective of this study is to determine the effective stormwater management strategies for mitigating elevated peak flows that causing flooding, four design storms with various return frequencies were selected to represent a spectrum of rainfall conditions. Design storm rainfall depths were obtained from Appendix I of SMC's Watershed Development Ordinance (SMC 2010) Rainfall Depth-Duration Frequency Tables for Lake County, which were based on Bulletin 70. Four design storms were selected for further evaluation (Table 4-1).

The rainfall depths were applied to the Huff Quartile Distributions in PCSWMM (CHI 2012). The Huff quartiles represent the typical rainfall distribution for four different storm duration ranges. The third Huff quartile is for storm duration greater than 12 hours and less than or equal to 24 hours.

Table 4-1. Rainfall depth of selected 24-hour duration design storm return periods

Return Period	24-hour Duration Rainfall Depth (inches)
1-year	2.35
2-year	2.8
10-year	3.88
25-year	4.75

4.1.2 Rainfall Runoff Baseline Modeling

Modeling may be used to help establish baseline conditions. Watershed models use site-specific spatial and temporal elements to characterize the rainfall runoff response. The watershed model time series represent the existing condition (or baseline conditions), which serves as the reference point from which stormwater improvement will be measured.

There are a wide variety of models available that have been used to assist stormwater management planning activities. Modeling approaches can range from simple to complex. The SWMM5 model was used to generate rainfall-runoff relationships in the Glen Flora Tributary pilot area, specifically because an existing, calibrated PCSWMM model developed by the ACOE for Glen Flora Tributary was available for reference.

SUSTAIN and SWMM each use slightly different modeling approaches to spatially discretize drainage areas. A unit area rainfall-runoff timeseries was derived from the SWMM model for input to *SUSTAIN*. Once the baseline model is established, proposed BMPs will be added to the baseline model to evaluate their potential impact.

Model Development

Development of the *SUSTAIN* baseline model consists of two sequential steps. The first step is to generate unit area rainfall-runoff time series for various land covers. The second step is to establish the model subwatershed and drainage network. The PCSWMM model developed by the ACOE was utilized to generate the unit area rainfall-runoff time series for thirteen types of land surfaces, including one impervious runoff time series and twelve pervious runoff time series, one for each of the *SUSTAIN* modeled subwatersheds (Figure 4-2). Figure 4-2 illustrate the *SUSTAIN* model subwatershed delineation and routing network. One area in the western part of the watershed was identified as disconnected from the Glen Flora Tributary based on the PCSWMM model, and was therefore not included in the analysis.

The *SUSTAIN* model includes twelve subwatersheds, fifteen junctions, nineteen conduits, and four existing storage ponds, including stormwater ponds and existing wetland areas (Figure 4-2). Three junctions were designated as assessment points (AP1, AP2, and AP3). AP1 is located at the outlet of subwatershed 3 and its drainage area includes subwatersheds 1, 2, 3 and 12; AP2 is located in subwatershed 9 upstream of the golf course; and AP3 is located at the outlet of the study area. Both AP1 and AP2 have experienced flooding during storm events. It should be noted that the PCSWMM model has a much finer discretization scale, and therefore some level of detail has been lost during this translation. Figure 4-3 illustrates the subcatchment delineation and routing network representation of the PCSWMM model. The PCSWMM model has 210 subcatchments, 4 stormwater storage ponds, and more than 500 conduits.

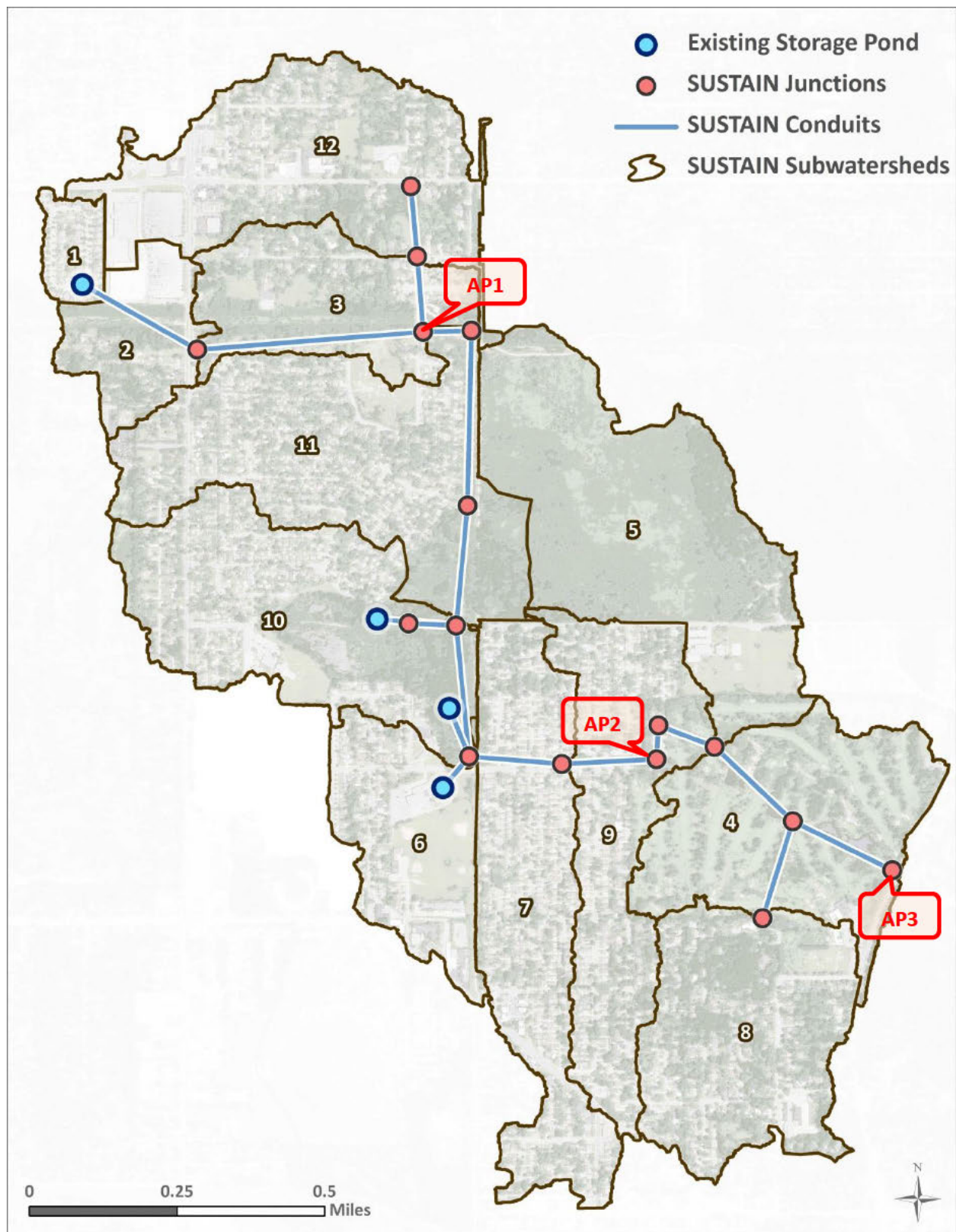


Figure 4-2. *SUSTAIN* model subwatershed delineation, routing network, and assessment points.

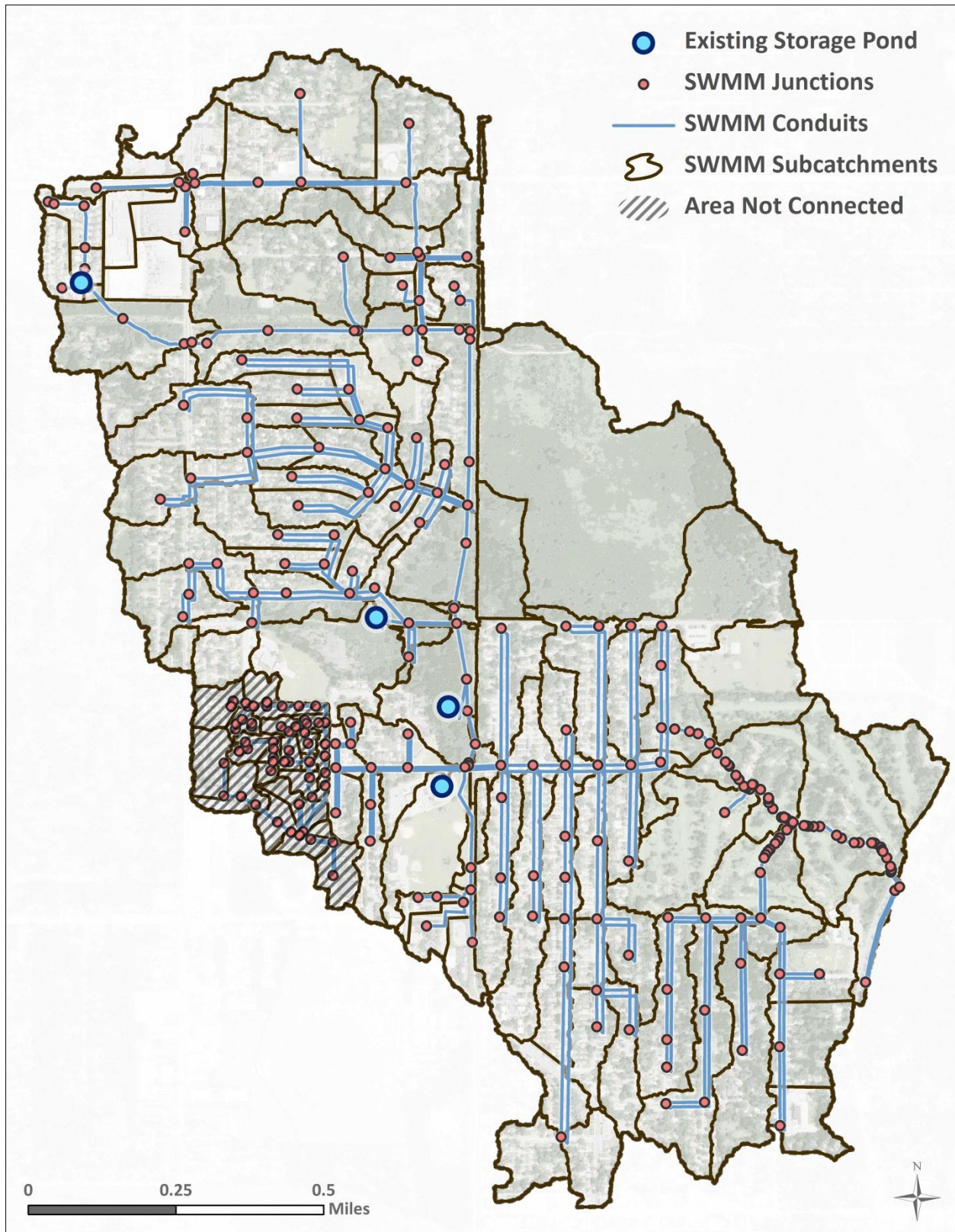


Figure 4-3. PCSWMM model subcatchment delineation and routing network.

Baseline Modeling Results

The simulated runoff volume for the four design storms at the three assessment points using the established *SUSTAIN* baseline model are summarized in Table 4-2. The values are compared with that of the benchmark PCSWMM model and percent differences are computed.

Table 4-2 shows the simulated runoff volumes at the study area outlet (AP3) by *SUSTAIN* is between 2 and 4 percent higher than the PCSWMM model. For AP1 and AP2, the difference is within -5 to 7 percent. The differences in runoff volume between the two models are mainly contributed to the different spatial resolutions of the soil infiltration parameters and representation of the drainage network. Peak flow values predicted by *SUSTAIN* were consistently higher than the PCSWMM model results due to the different routing methods used and different drainage network represented in the two models. In *SUSTAIN*, considering the main objective of this project is to evaluate the relative peak reduction effectiveness, instead of the absolute peak flow rates, a drainage network of 19 conduits and kinematic wave routing method are used to simplify the routing simulation and reduce the computation time demand. This simplification is acceptable since we are most interested in the relative differences between an existing condition scenario and BMP scenarios.

Table 4-2. Comparison of simulated runoff volume of PCSWMM and *SUSTAIN* models by design storms

Runoff Volume (cubic ft)	PCSWMM			SUSTAIN			Percent Difference (%)		
	AP1	AP2	AP3	AP1	AP2	AP3	AP1	AP2	AP3
1-yr, 24-hr	827,766	2,804,211	3,357,324	884,629	2,696,427	3,421,264	7%	-4%	2%
2-yr, 24-hr	1,008,711	3,390,777	4,089,573	1,074,749	3,343,569	4,262,707	7%	-1%	4%
10-yr, 24-hr	1,530,810	5,019,966	6,347,754	1,571,244	4,933,814	6,492,832	3%	-2%	2%
25-yr, 24-hr	1,990,611	6,714,441	8,473,968	2,023,480	6,384,488	8,676,925	2%	-5%	2%

5. Identify Potential BMPs

Identifying the appropriate suite of BMPs for analysis in *SUSTAIN* requires an understanding of the watershed, sources of runoff, available treatment area, and feasibility of BMP construction. An evaluation of the land uses determined that there were two different types of residential areas in the Glen Flora Tributary pilot area, one which includes traditional street curb and gutter with small lots and another which has a rural section road design and large open lots (Figure 5-1 and Table 5-1). BMPs will differ for each of these residential areas.

Table 5-1. Summary of residential area characteristics

Residential BMP Area	Total Area (acres)	Impervious Area (%)	Number of Homes	Average Parcel Size (acres)	Average Front Yard (sq ft)	Average Roof Area (sq ft) ^a	Average Driveway Area (sq ft)
1	476.9	49	2,475	0.17	1,200	1,300	960
2	52.1	13	70	0.71	2,920	1,500	1,260

a. Area includes garage roof when attached to home (most houses have detached garages and the area is not included)

5.1 BMP Selection

BMPs for the Glen Flora Tributary pilot area were selected based upon the characteristics of each land use. The selection of BMPs is dependent upon the suitability of the BMPs for each area based upon site conditions and performance goals. Examples of some of the BMPs that can be modeled in *SUSTAIN* include bioretention, rain barrels, cisterns, detention ponds, infiltration trenches, vegetative swales, porous pavement, and green roofs.

The majority of the Glen Flora Tributary pilot area has a high water table which can be seen at the surface in the large wetland complexes along the Robert McClory bike path. A distance of 3-5 feet is typically recommended between any BMP which promotes infiltration and the seasonally high water table. Because of these natural constraints, BMPs that promote high levels of infiltration (e.g., infiltration basins and trenches, dry wells) were eliminated from the suite of potential BMPs. BMPs that required significant excavation (e.g., underground storage) were also eliminated from the suite of potential BMPs. The following BMPs were considered for this pilot area:

- Bioretention (bioswale/pond)
- Rain garden
- Porous pavement
- Rain water harvesting (rain barrel)
- Green roof
- Regional ponding
- Conversion to native vegetation

Each of the BMPs was evaluated for applicability in the Glen Flora Tributary pilot area on the basis of a review of aerial imagery and field reconnaissance. Candidate locations were selected according to available land area and proximity to sources of runoff and pollutants.

The assessment of BMP opportunities also involved analyzing various combinations of practices (i.e., treatment trains). Using a treatment train approach, stormwater management begins with simple methods that minimize the amount of runoff that occurs from a site. Typically those practices involve either on-site interception (e.g., rain barrels) or on-site treatment (e.g., bioswale, porous pavement). The following sections provide a description of each BMP and the considerations made during the applicability analysis.

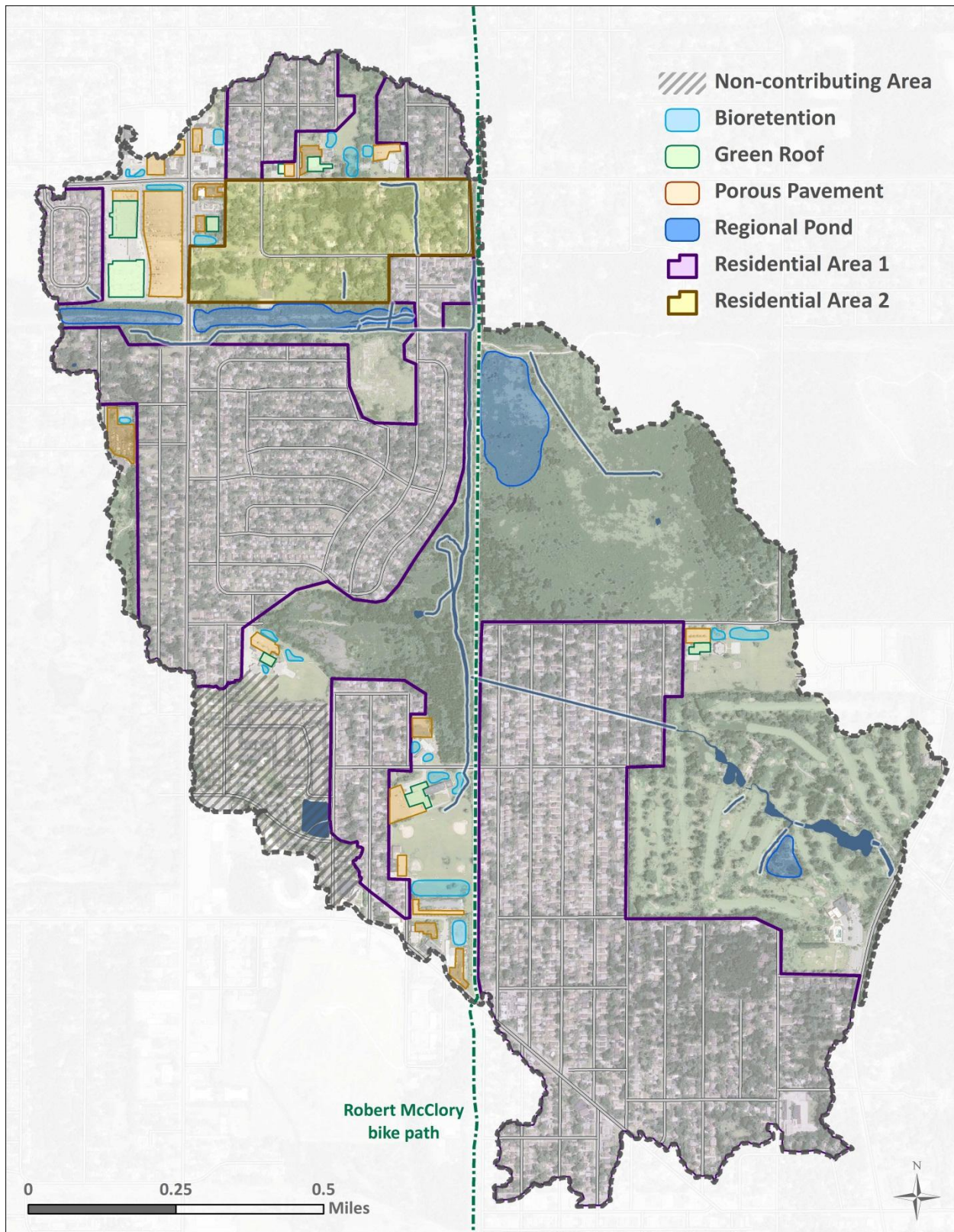


Figure 5-1. BMP evaluation.

5.1.1 Bioretention

Bioretention facilities are designed to capture and retain runoff from local paved roads, driveways, and the front half of parcels. Bioretention facilities can be linear features constructed adjacent to roadways, small ponding areas in the form of curb bump outs, or larger ponding areas. Although potential bioretention areas are identified in Figure 5-1, bioretention is modeled in *SUSTAIN* as an aggregate practice, which means that specific locations are not identified in the model. However, within each discrete drainage area, a bioretention template was designed and applied to treat the relevant land sources upstream. With that approach, the fraction of area treated or untreated was also defined. BMP sizing and treatment distribution are the optimization variables of concern.

Potential locations for bioretention were identified through aerial imagery analysis. There are limited areas within the residential areas to place bioretention due to small front yards and the presence of mature trees. The area modeled for bioretention facilities includes up to 40 percent of the linear area adjacent to the paved roads in Residential Area 2, with an average width of ten feet. In addition, bioretention facilities are included in most of the commercial and institutional properties (Figure 5-1).



Figure 5-2. Bioretention example.

Bioretention facilities are sized according to the available land area based on aerial imagery analysis and best professional judgment and are assumed to encompass up to 6.5 acres of the watershed. Bioretention facilities are designed for one-half foot of ponded depth and three feet of plant and soil media, and include free-flowing underdrains set three feet below the bottom of the basin. In Residential Area 2, the drainage area to bioretention includes the front half of roofs, driveways, front yards and streets. Drainage area to bioretention on commercial and institutional properties is comprised of parking lot imperviousness. The BMPs can treat up to 34.3 acres of impervious and 4.7 acres of pervious surfaces.

5.1.2 Rain Garden

Rain gardens are also modeled as an aggregate practice. Rain garden areas are assumed to be located in front yards of residential areas and are designed to serve the overflow from rain barrels and runoff from the surrounding area throughout all residential areas. Since gutters typically route rooftop runoff to the four corners of a house, it is assumed that one-half of the rooftop is routed to the front yard and can therefore be routed to the rain garden. In addition, one-half of the front yard is assumed to be routed to each rain garden since it is unlikely that runoff from the entire yard could be captured. Driveways are also routed to rain gardens through a trench drain at the bottom of the driveway, thereby capturing this impervious area prior to discharging into the road.



Figure 5-3. Example residential rain garden

Rain gardens are assumed to be constructed and maintained by the homeowner with little costs associated with design. A two foot soil amendment is assumed with no underdrain. Front yard size was considered when setting the size of the rain garden (150 square feet). It is assumed that a maximum of 10 percent of homes in the residential area could be served by rain gardens in combination with a rain barrel. A total of 16.6 acres (10.6 impervious acres and 6 pervious acres) could be treated by rain gardens.

5.1.3 Porous Pavement

Porous pavement was assumed to be applicable throughout the pilot area for both roads in the residential areas and parking lots in commercial areas. The modeled porous pavement design for streets includes two strips of porous pavement, each four feet wide and located along both sides of the curb (Figure 5-4). An underdrain is included two feet below the pavement. The contributing drainage area includes the pavement itself, driveways, and contributing roof and urban lawn areas. Porous pavement would treat a maximum of 187.0 impervious acres and 72.9 pervious acres. Roads are delineated using GIS, and driveway, roof, and front yard areas are estimated using a representative number of homes in each of the residential BMP areas.



Figure 5-4. Porous pavement example.

Porous pavement can also be used effectively in parking lots. Sixty percent of each paved parking lot was considered for porous pavement installation, which assumes that driving lanes remain asphalt or concrete and the parking spots are made permeable. All parking lots are assumed to have underdrain systems. The drainage area is represented by the entire parking lot area.

5.1.4 Rain Barrel

Rain barrels provide for storage of runoff. Following rainfall events, the water stored in rain barrels and cisterns can be used for irrigating vegetation. Rain barrels are typically applied in residential areas while cisterns are used in commercial or institutional areas. It was assumed that up to 10 percent of homes in the residential area could be retrofitted with up to two rain barrels. All homes that contain a rain garden are assumed to have two rain barrels. The sequence assumes that the entire rain barrel volume is released by opening a bottom orifice two days after the end of a storm. The stored water is used to irrigate bioretention vegetation. The rain barrel capacity at any point during the simulation is a function of the amount of water released after a previous event. If rain barrels are filled to capacity, back-to-back precipitation events can show bypass, with no rain barrel benefit. During cold-weather conditions, the rain barrels are assumed to be disconnected from rooftop downspouts. The standard size of rain barrels used for this pilot was 55 gallons, with a maximum of two units per home. The drainage area to each rain barrel is assumed to be equal to one-quarter of the roof area.



Figure 5-5. Green roof example.

5.1.5 Green Roof

Green roofs can typically be placed on any flat roof surface, assuming the roof can support the additional weight. Potential green roof locations were identified throughout the pilot area using

aerial photography. It was assumed that flat roofs would have the structural support necessary to carry a green roof, which results in an overestimation of the maximum potential area suitable for green roofs. The drainage area to green roofs is assumed to include the entire roof surface. An extensive green roof was assumed.

5.1.6 Regional Ponding

The potential for off-line regional ponding was identified throughout the pilot area in existing open space areas. Regional ponds are proposed adjacent to the North Shore Ditch and within the golf course. These ponds would serve to provide offline detention in the form of wetlands or bioretention, modeled as a detention basin in *SUSTAIN*. The contributing drainage area includes all area upstream of the regional pond. Table 5-2 summarizes the proposed regional pond information, including the maximum pond surface area, contributing subwatersheds, contributing drainage area, and drainage area to pond area ratio.

Table 5-2. Regional ponds

	Subwatershed			
	2	3	4	5
Maximum pond area (ac.)	2.88	6.84	1.68	12.58
Contributing subwatersheds	1, 2	1, 2, 3	8	1, 2, 3, 12
Contributing drainage area (ac.)	45.1	104.0	87.5	207.7
Drainage area : Pond area ratio	16 : 1	15 : 1	52 : 1	17 : 1

5.1.7 Conversion to Native Vegetation

Native vegetation has the ability to intercept rainfall and promote infiltration and evapotranspiration. The conversion of residential lawn to native vegetation was modeled by replacing the residential pervious land runoff time series with a runoff time series for native vegetation. The effectiveness of converting 10 percent (28.6 acres) and 20 percent (57.2 acres) of the lawn area was simulated. Figure 5-6 plots the peak flow rates at the three assessment points for the four selected design storms. It shows that with even a 20 percent conversion, the peak flow reduction is insignificant (less than 1.5 percent) for all design storms. Other continuous modeling studies of this sort have shown that even under predeveloped (natural) conditions, peak flow is difficult to control under saturated conditions without supplementing storage potential in some way. It should also be recognized that 20 percent (57.2 acres) of the residential lawn area represents only 5.7 percent of the total study area. Therefore it is expected that solely converting part of the residential lawn area to native vegetation without diverting impervious runoff to the converted area will not significantly reduce runoff peak flows.

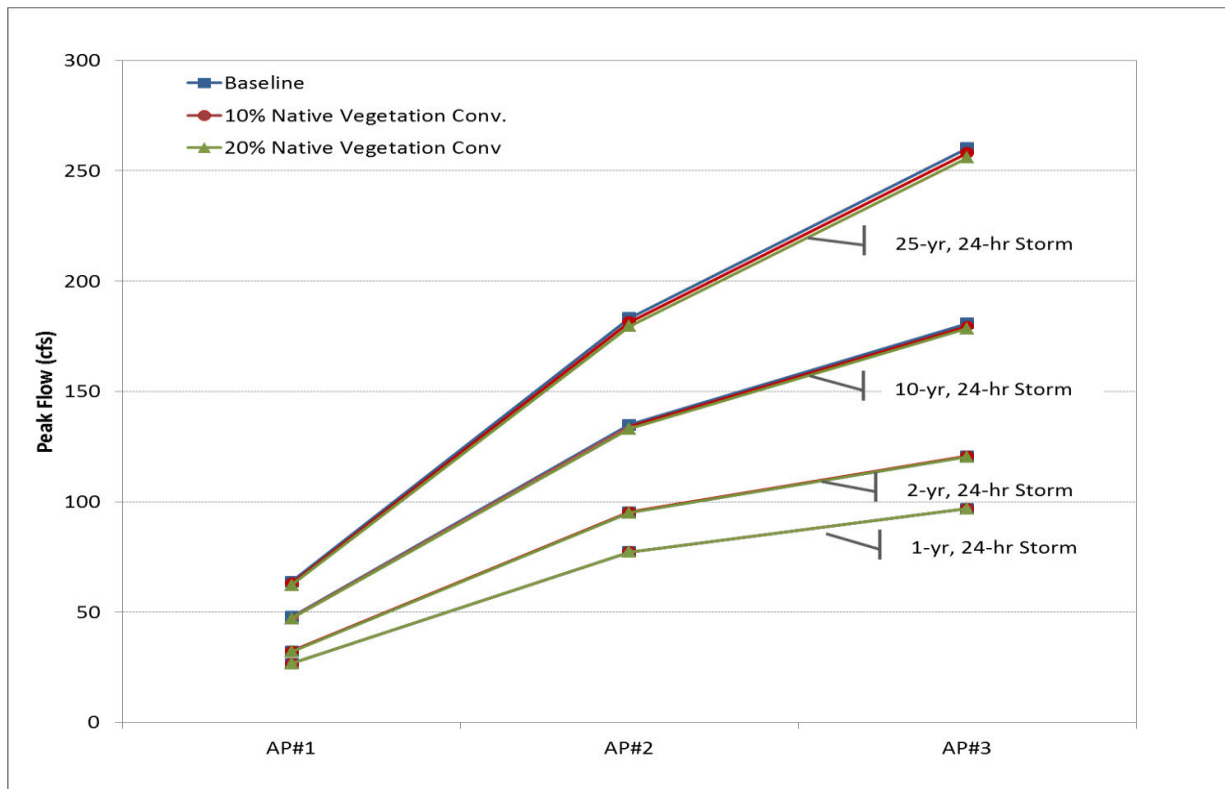


Figure 5-6. Impact of native vegetation conversion on peak flow reduction.

6. Determine BMP Configuration and Performance

BMPs are simulated in *SUSTAIN* according to design specifications, with the performance modeled using a unit-process parameter-based approach. That contrasts with and has many advantages over most other techniques that simply assign a single percent effectiveness value to each type of practice. *SUSTAIN* predicts BMP performance as a function of its physical configuration, storm size and associated runoff intensity and volume, and moisture conditions in the BMP.

Many of the BMPs were simulated in aggregate, recognizing the scale and model resolution of the watershed model. The aggregate approach is a computationally efficient and analytically robust approach that *SUSTAIN* provides for evaluating relative management practice selection and performance at a small subwatershed scale.

An aggregate BMP consists of a series of process-based optional components, including on-site interception, on-site treatment, routing attenuation, and regional storage/treatment. Each aggregate BMP component evaluates storage and infiltration characteristics from multiple practices simultaneously without explicit recognition of their spatial distribution and routing characteristics in the selected watershed. For example, certain rain barrels in the aggregate BMP network are modeled in series with rain gardens, and serve residential rooftop runoff area.

In lieu of modeling each individual BMP, such as a rain barrel or bioretention area, the aggregate approach allows the user to define generalized application rules on the basis of BMP opportunity and typical practice. The role of optimization is to determine the relative size (or number) of each BMP component that achieves the defined management objective at the lowest cost. For this application, the aggregate practice includes six component practices—rain barrel, rain garden, bioretention, porous pavement, green roof, and regional ponds. Figure 6-1 is a schematic diagram of aggregate components, drainage areas, and practice-to-practice routing networks.

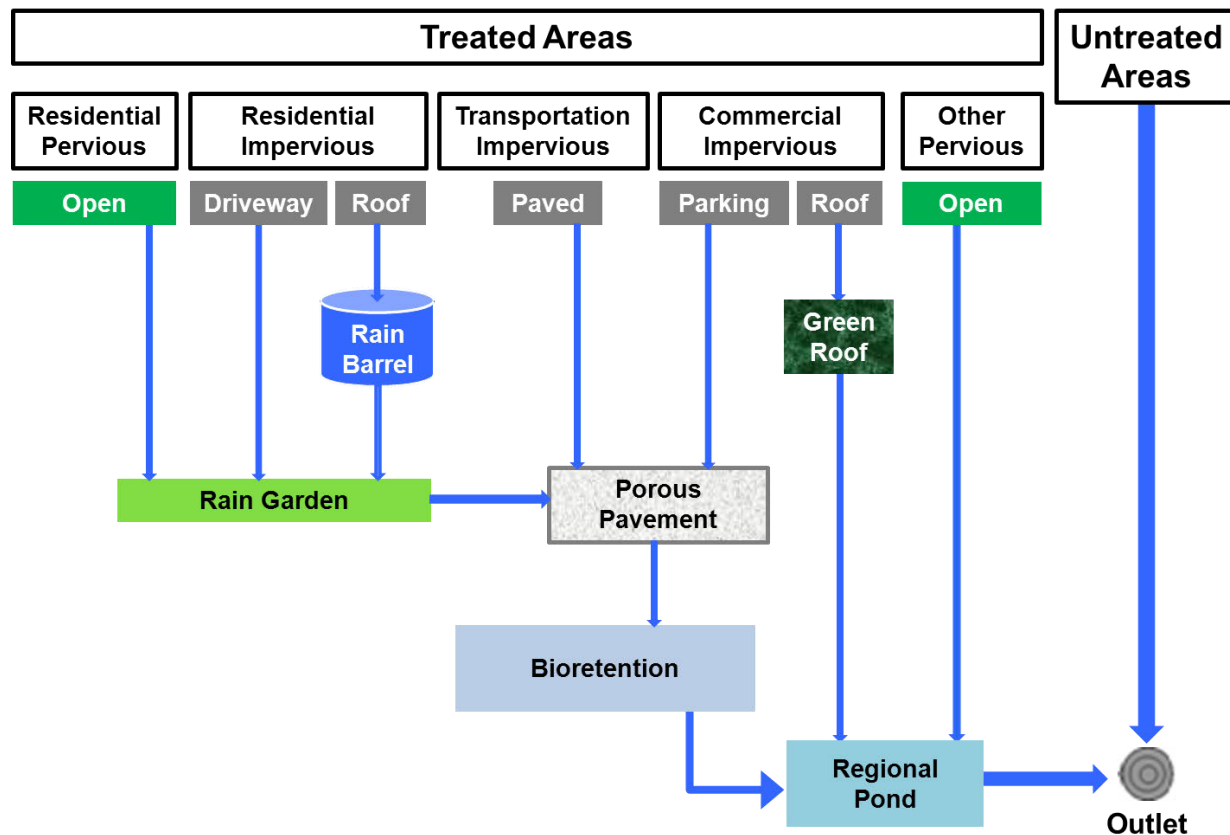


Figure 6-1. Aggregate BMP schematic identifying treatment train options.

As shown in Figure 6-1, the rain barrel component collects runoff from rooftops (as part of the impervious surfaces) in residential areas. Outflow and bypass from these BMPs is assumed to flow directly to rain gardens, as are front yards and driveways. Other impervious areas can be treated by porous pavement or green roofs, and outflow is then routed to bioretention practices or regional ponds.

Outflows from regional ponds and runoff from any type of land use that is not subject to treatment by aggregate practice components are routed directly to the outlet. Note that the aggregate BMP setup is a tool to determine which BMP(s) are most efficient at achieving an environmental outcome without representing each individual BMP explicitly (e.g., representing rain barrels for each roof in the study area). The configuration of BMP routing in the aggregate setup are meant to represent a treatment train that makes sense based upon the BMP design characteristics and assumed topographic conditions of the most likely drainage network. The aggregate BMP network represents the maximum potential sizing and routing for BMPs in a study area. Just because a type of BMP is included in the aggregate, does not mean that it will be favored when optimization analysis is performed, as described below.

The objective of this effort was to identify combinations of practices that maximize peak flow reduction while minimizing the lifecycle cost of the associated group of BMPs. To run the optimization analysis, a set of decision variables was identified to explore the best possible combinations of the various BMP practices. For this analysis, the decision variables consisted of the following:

- Number of fixed-size rain barrel and rain gardens
- Surface area of regional ponds, bioretention, porous pavement, and green roof

Because the decision variable values can range anywhere between zero to a maximum number or size, it is possible for one component in the treatment train to never be selected if it is not cost-effective toward achieving the objective. For example, even though the aggregate BMP setup includes rain barrels, if rain gardens are found to be a more cost-effective solution under all conditions, all roof runoff will be directly routed to available rain gardens. In other words, the aggregate BMP provides a menu of options that might or might not be selected, depending on cost-effectiveness.

Table 6-1 summarizes the maximum extent of each practice determined through aerial photography analysis, field reconnaissance and on the basis of best professional judgment as described in Section 5. Those values define the upper boundary of the optimization search space. Table 6-2 presents the maximum BMP extents by subwatershed in *SUSTAIN* model (Figure 6-2). The maximum drainage area columns are not additive since several of the drainage areas include the same source area. For example, the rain barrel drainage area is equal to one-half of the roof while the rain garden drainage area includes that same roof area plus the driveway and front yard. There are a total of 448 acres of impervious area and 529 acres of pervious area in the watershed. All of subwatersheds 1, 2, 3, 8, and 12 are treated by regional ponds. Approximately 50 percent of the residential area is treated by BMPs. The remaining untreated residential area includes the back half of roofs and backyards. The physical configuration data and infiltration parameters for each BMP component are listed in Table 6-3.

Table 6-1. Maximum extent of BMPs

BMP	Maximum BMP Extent (unit or acre)	Maximum Drainage Area (impervious acres)	Maximum Drainage Area (pervious acres)	Maximum Drainage Area (acres)
150 ft ² Rain Garden (unit)	255	10.6	6.0	16.6
55 Gallon Rain Barrel (unit)	510	4.1	0	4.1
Bioretention (acres)	6.5	34.2	4.7	38.9
Porous Pavement Roads (acres)	14.9	187.0	72.9	259.9
Porous Pavement Parking Lots (acres)	10.7	17.8	0	17.8
Green Roof (acres)	6.2	6.2	0	6.2
Regional Pond (acres)	24	158.9	136.3	295.2 ^a
Conversion to Native Vegetation (acres)	28 - 57	0	28 - 57	28 - 57

a. Total area of subwatersheds 1, 2, 3, 8, and 12.

Table 6-2. Maximum extent of BMPs by subwatershed in *SUSTAIN* model

BMP	Subwatershed											
	1	2	3	4	5	6	7	8	9	10	11	12
150 ft ² Rain Garden (unit)	6	7	18	--	--	10	44	37	34	29	42	29
55 Gallon Rain Barrel (unit)	11	14	36	--	--	19	88	74	68	58	83	58
Bioretention (acres)	--	0.10	0.15	--	0.88	2.84	--	--	--	0.39	--	2.13
Porous Pavement (acres)	0.39	2.57	0.64	--	0.38	2.77	3.04	1.71	2.15	2.52	3.83	5.60
Green Roofs (acres)	--	2.00	--	--	0.36	0.74	--	--	--	0.24	--	2.89
Regional Ponds (acres)	--	2.88	6.84	1.68	12.58	--	--	--	--	--	--	--

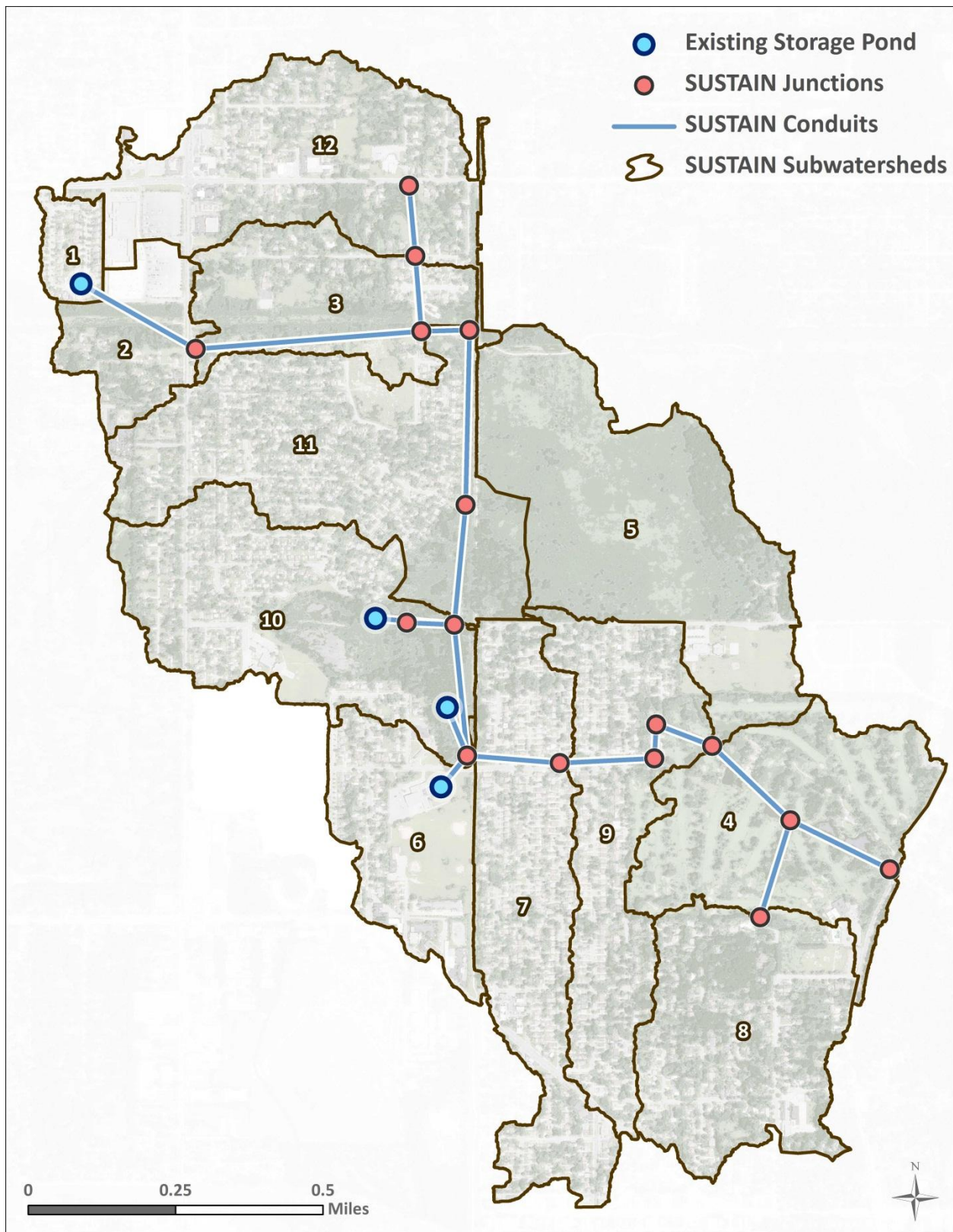


Figure 6-2. *SUSTAIN* model subwatersheds.

Table 6-3. BMP configuration parameters

Parameter	Rain Barrel	Rain Garden	Bio-retention	Regional Pond	Porous Pavement	Green Roof
Physical Configuration						
Unit size	55 gal	150 ft ²	N/A	N/A	N/A	N/A
Design drainage area (square feet)	350	2,840	N/A	N/A	N/A	N/A
Substrate depth (ft)	N/A	2	2	1.5	2	0.67
Underdrain storage depth (ft)	N/A	N/A	1	NA	1	0.1
Ponding depth (ft)	N/A	0.5	0.5	3	0.1	0.1
Infiltration						
Substrate layer porosity	N/A	0.4	0.4	0.4	0.45	0.4
Substrate layer field capacity	N/A	0.25	0.25	0.25	0.15	0.4
Substrate layer wilting point	N/A	0.1	0.1	0.1	0.05	0.1
Underdrain gravel layer porosity	N/A	N/A	0.5	N/A	0.5	0.5
Vegetative parameter	N/A	1	1	1	N/A	0.6
Background infiltration rate for each HSG (in/hr)	N/A	B – 0.5 C – 0.3 D – 0.1	B – 0.5 C – 0.3 D – 0.1	B – 0.5 C – 0.3 D – 0.1	B – 0.5 C – 0.3 D – 0.1	N/A
Media final constant infiltration rate (in/hr)	N/A	0.5	0.5	0.5	1	1
Initial soil moisture	N/A	0.15	0.15	0.15	0.15	0.15

Infiltration parameters were determined on the basis of the assumed soil substrate. The background infiltration rate refers to the infiltration rate of the native soils below the engineered media and varies dependent upon the predominant hydrologic soil group within each subwatershed. The vegetative parameter, or the percent vegetative cover, and wilting point values were provided by Tetra Tech, Inc. (2001). Wilting point is defined as the minimal soil moisture required to prevent vegetation wilting.

7. BMP Costs

Identifying BMP costs is an important step in the BMP Optimization Approach because resource constraints may limit the type and number of BMPs that can be used to achieve program goals. BMP costs are evaluated with estimated reductions to select the final set of BMPs that are most cost-effective. There are three types of BMP costs to consider over the life cycle of a BMP:

- Probable Construction Costs – The initial cost to construct the BMP.
- Annual Operation & Maintenance – The annual costs to maintain the BMP.
- Repair & Replacement Costs – The additional costs to repair or replace the BMP.

A standard unit cost was defined for each BMP category, since the range of BMPs was unknown and expected to vary significantly. Each unit cost was converted to 2012 dollars by applying a three percent inflation rate by the number of years from the published year of the cost data to 2012. A discount rate of 3 percent was used for converting annual O&M and repair and renewal costs to present value.

The lifecycle period was defined as 20-years to take into account costs for replacing some BMPs. Several of the published sources used to derive costs data for structural practices to be input into *SUSTAIN* defined engineering and design or contingency factors based upon a percent of the base construction cost, while other published sources intentionally omitted them. A default 15 percent engineering and design cost factor and 25 percent contingency cost factor were assigned to probable construction costs when no values were provided for all structural practices without available cost data. No land, capital, administration, demolition, or legal cost factors were defined for any of the probable construction costs. Table 7-1 presents the lifecycle costs for each of the BMPs.

The following sources were reviewed when defining the lifecycle costs:

- BMP and Low Impact Development Whole Life Cost Models Version 2.0. Water Environment Research Foundation (WERF 2009).
- Lake County Stormwater Management Commission, Central Permit Facility Fact Sheet.
- National Green Values Calculator, Center for Neighborhood Technology (Center for Neighborhood Technology 2009).
- The Cost and Effectiveness of Stormwater Management Practices, University of Minnesota (Weiss et al. 2005).
- Low Impact Development for Big Box Retailers. Prepared for U.S. Environmental Protection Agency (Low Impact Development Center 2005).
- Low Impact Development Manual for Michigan, Southeast Michigan Council of Governments.

Additional Tetra Tech projects and best professional judgment were also considered when defining the range of lifecycle unit costs.

Table 7-1. BMP lifecycle costs

Parameter	Rain Barrel	Rain Garden	Regional Pond	Bio-retention	Porous Pavement	Green Roof
Life Cycle Cost Data						
Lifecycle Unit Cost [A+B+C] (NPV)	\$166 ea.	\$1,500 ea.	\$10/ft ²	\$36/ft ²	\$11/ft ²	\$45/ft ²
A) Probable Unit Cost	\$95.00 ea.	\$750	\$8	\$29	\$7	\$28
B) Annual O&M (NPV)	\$0	\$0	\$2	\$7	\$4	\$16
C) Repair & Replacement (NPV)	\$71 ea.	\$750	\$0	\$0	\$0	\$1
BMP Lifecycle Period	10-yrs	10-yrs	--	--	--	--

NPV – Net Present Value; -- indicates that lifecycle is greater than the 20-year period

8. BMP Optimization Analysis

The final step in the BMP Optimization approach is to evaluate and prioritize the potential BMPs based upon costs, BMP performance, and other goals of stormwater management planning. The objective of optimization modeling in *SUSTAIN* for the Glen Flora Tributary pilot area was to evaluate peak flow reduction of the four selected design storms using the previously described suite of practices. In assessing the study objective this analysis will:

- Develop a cost-effectiveness curve for each design storm that shows the tradeoffs between cost and peak flow reduction for increasing management targets
- Prioritize BMP selection for selected management levels of interest
- Summarize cost, modeled peak flow reduction, and modeled flow volume reduction for select points along the cost-effectiveness curve

8.1 Optimization Results

For the comparison of BMP effectiveness (i.e., peak flow reduction), an existing condition scenario was considered as a baseline for each of the design storm events. The runoff from various land covers were derived using the unit-area SWMM model. Using the previously described BMPs, a cost-effectiveness relationship was simulated and optimized using *SUSTAIN*. Figure 8-1 shows the relationship between peak flow reduction and lifecycle cost for the four design storms in the Glen Flora pilot area.

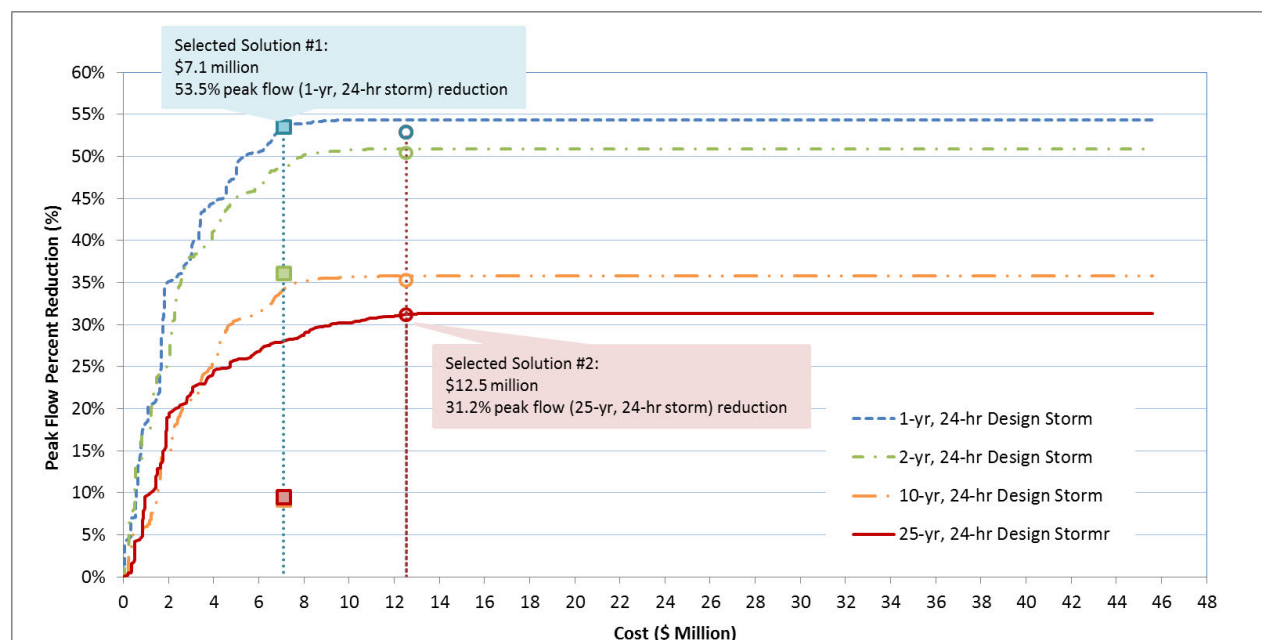


Figure 8-1. Cost-effectiveness curves for reducing design storm peak flow at assessment point AP3.

The cost-effectiveness curve shows that, at the same cost, higher peak flow reductions can be achieved for smaller storms. All four curves reached a plateau that demonstrates no increase in peak flow reduction as costs increase. The maximum peak flow reductions modeled are summarized in Table 8-1. The overall watershed goal of 75 percent reduction in peak flow is not met using the suite of BMPs included in this analysis. A maximum peak flow reduction of 54.4 percent for the 1 year event and 31.3 percent for the larger 25 year event were determined when all potential BMPs were modeled (100 percent utilization). This indicates that the maximum extent of BMPs is insufficient to treat to higher levels.

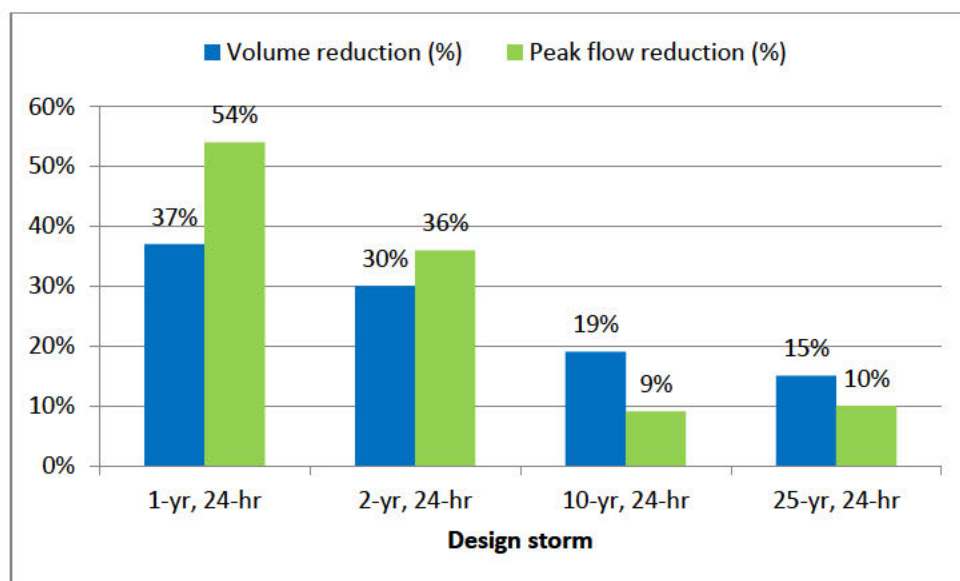
Table 8-1. Maximum modeled peak flow reductions

Design Storm	Maximum Peak Flow Reduction (%)
1-year, 24-hr	54.4%
2-year, 24-hr	50.9%
10-year, 24-hr	35.8%
25-year, 24-hr	31.3%

8.1.1 Selected BMP Solutions

Two possible solutions were selected to provide a refined analysis of the cost-effectiveness curves represented as the blue square and red circle in Figure 8-1. Solution #1 is the near optimal solution to maximize the peak flow reduction with the minimum cost for the 1 year, 24-hour design storm. Similarly, solution #2 is the near optimal solution that achieves the highest peak flow reduction for the 25 year, 24-hour design storm.

These two solutions were then evaluated for their peak flow reductions compared with the other design storms. The results for solution #1 are shown as squares along same vertical (cost) line, color coded to correspond to their design storms. The squares are far below the cost-effectiveness curves of their respective design storms. The associated peak flow and volume reductions for solution 1 and 2 are provided in Figure 8-2 and Figure 8-3.

**Figure 8-2. Peak flow and volume reduction at AP3, solution 1 (optimized to 1-year, 24 hour event).**

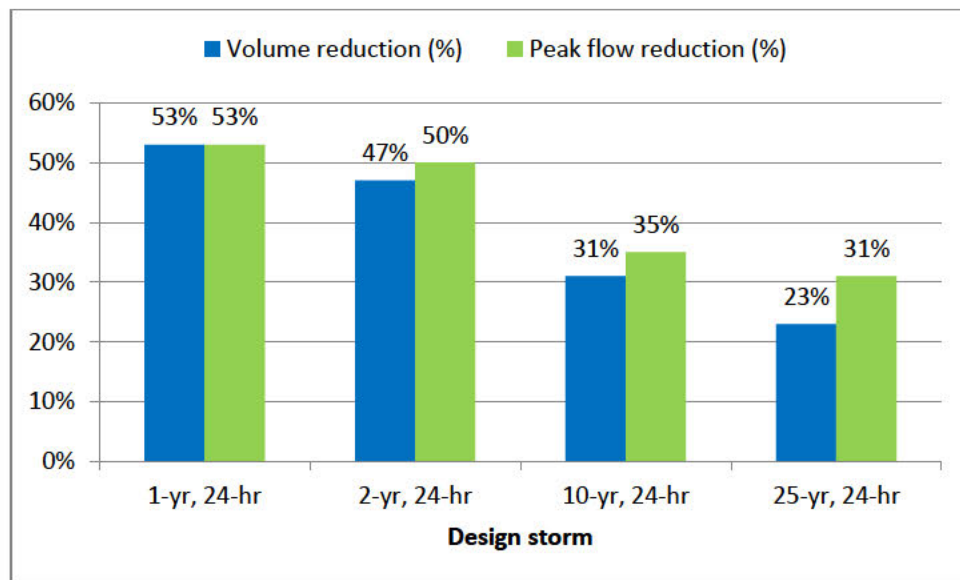


Figure 8-3. Peak flow and volume reduction at AP3, solution 2 (optimized to 25-year, 24 hour event).

The cost-effectiveness curve indicates that solution #1, which was selected to control the 1-year 24-hour storm, has inferior peak flow control effectiveness for larger storms. The circles representing solution #2 indicate that the peak flow reduction percentages for their respective design storms are very close to the cost-effectiveness curves. This means that solution #2, which was optimized to control the 25-year 24-hour storm, has close to optimal peak flow control effectiveness for smaller storms. The implication of this finding is that the BMP solutions that are optimized to control smaller storms will not be cost-effective for controlling larger storms, whereas BMP solutions optimized to control larger storms will be effective for mitigating the peak of smaller storms. Figure 8-4 includes the modeled hydrographs for both the 1-and 25-year design storms under an existing conditions scenario and solution 1 and 2 results at AP3. Appendix A contains hydrographs for all assessment points.

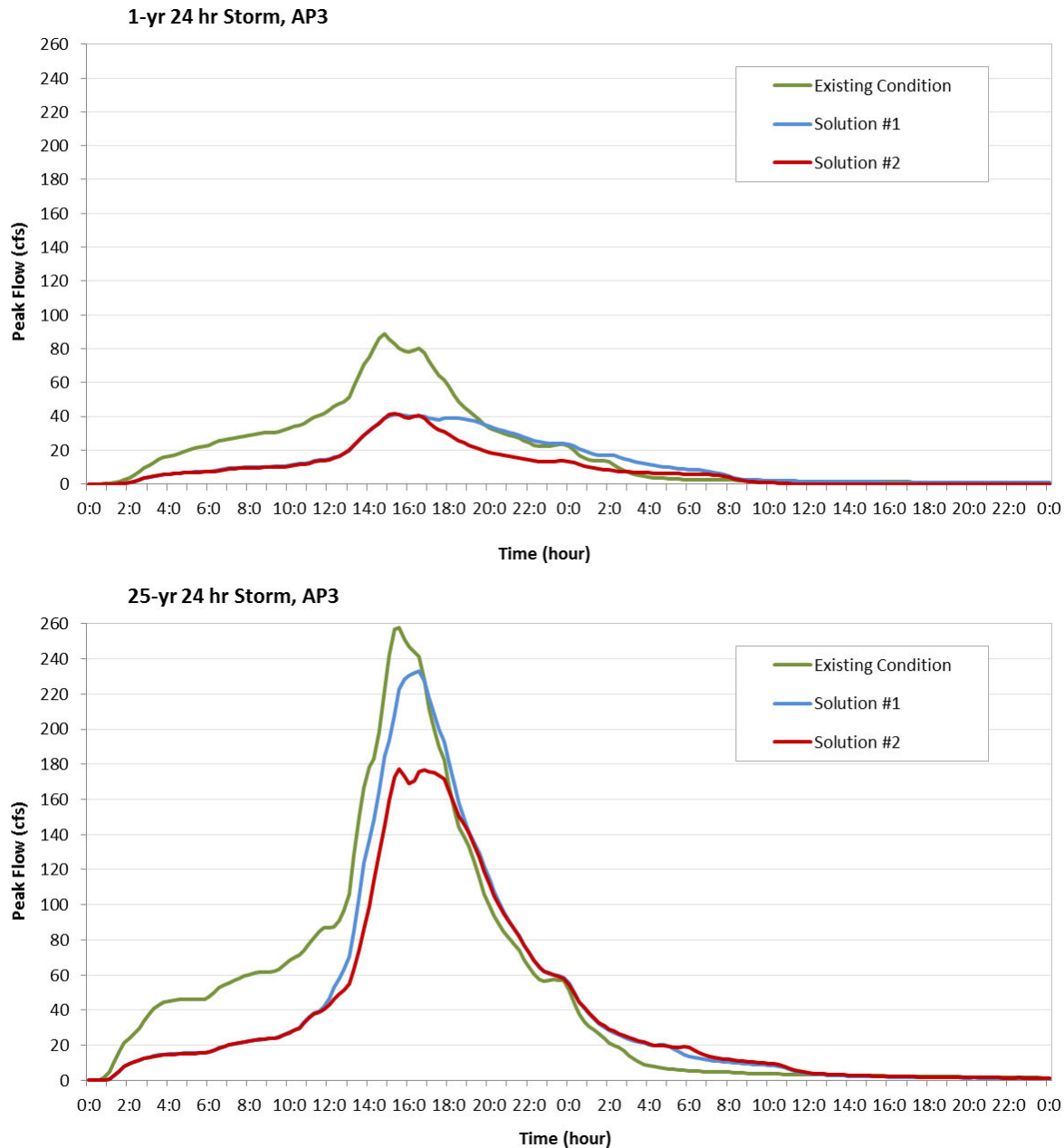


Figure 8-4. Modeled hydrographs for 1- and 25- year events.

The BMP composition of the two selected solutions are shown in Figure 8-5 and Figure 8-6 as percent utilization of each BMP type by subwatershed, and in Table 8-2 and Table 8-3 as the number of BMP unit and BMP surface areas by subwatershed (refer to Figure 6-2 for subwatershed locations). These figures and tables reveal that regional ponds are prioritized in both solutions. The results show that in the subwatersheds treated by regional ponds, the distributed BMPs are less utilized than in the subwatersheds that are not treated by regional ponds. This trend is most obvious for solution #1 which was designed to control the 1-year 24-hour storm. As shown in Figure 8-5, the distributed BMPs in subwatersheds 1, 2, 3, 10, and 12 were not selected at all, and in subwatershed 8, which is treated by regional pond in subwatershed 4, only 20 percent of porous pavement was utilized. This is because the regional ponds in subwatershed 3 and 5 are large enough to control the peak flow resulting from upstream watersheds.

without utilizing the distributed BMPs. The pond in subwatershed 4, even at 100 percent utilization, is not large enough, thereby requiring distributed BMPs in the upstream contributing drainage area (subwatershed 8). The same trend holds true for solution #2, although the need to control a larger storm does require additional distributed BMPs in the subwatersheds.

Another finding is that, among the distributed BMP types, porous pavement is the most cost-effective for peak flow reduction, followed by rain barrel and rain garden, then bioretention/bioswale. Green roofs are the least favorite and are not chosen in either solution. This outcome is largely dictated by BMP costs and their peak flow attenuation capabilities.

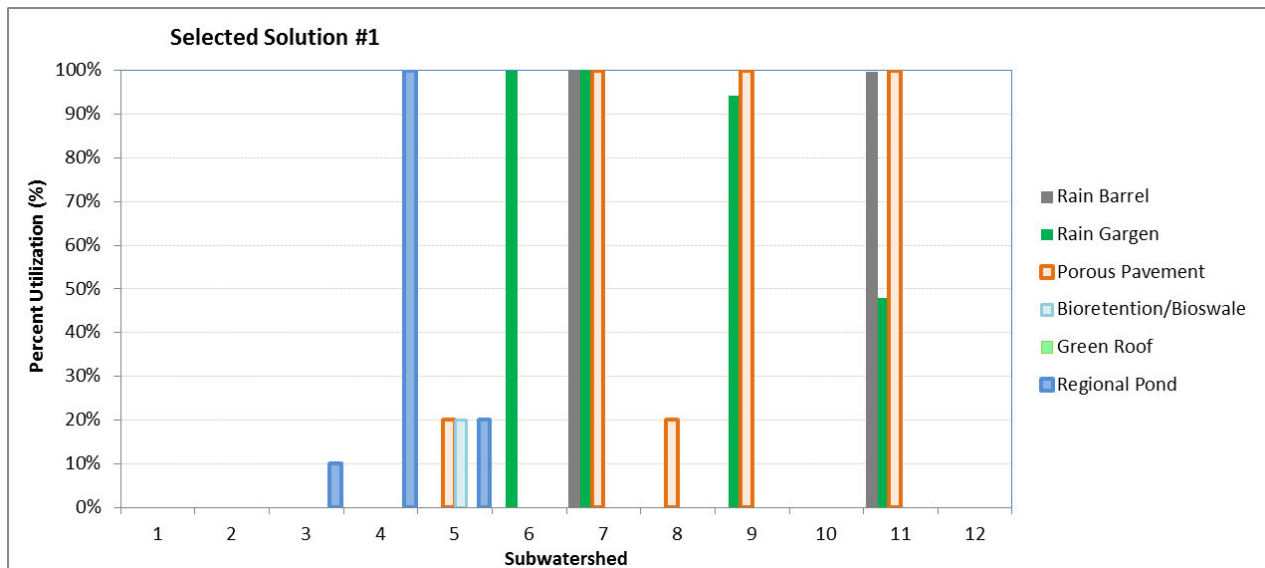


Figure 8-5. BMP percent utilization of selected solution #1.

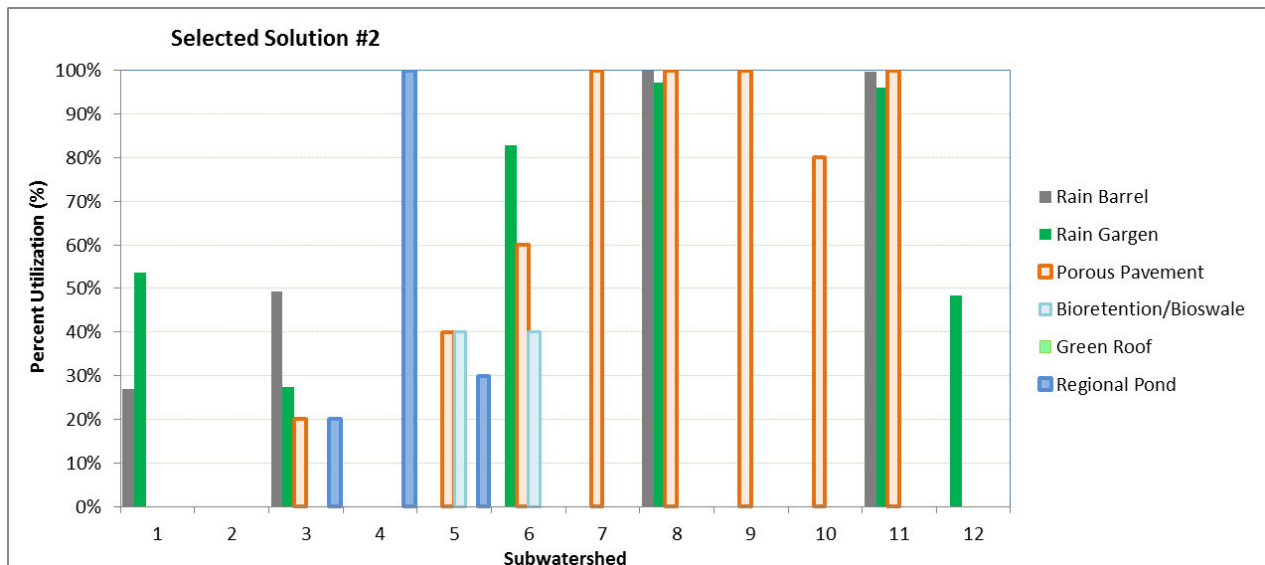


Figure 8-6. BMP percent utilization of selected solution #2.

Table 8-2. BMP composition of selected solution #1

BMP	Subwatershed											
	1	2	3	4	5	6	7	8	9	10	11	12
150 ft ² Rain Garden (unit)	0	0	0	--	--	10	44	0	32	0	20	0
55 Gallon Rain Barrel (unit)	0	0	0	--	--	0	88	0	0	0	83	0
Bioretention (acres)	--	0.00	0.00	--	0.18	0.00	--	--	--	0.00	--	0.00
Porous Pavement (acres)	0.00	0.00	0.00	--	0.08	0.00	3.04	0.34	2.15	0.00	3.83	0.00
Green Roofs (acres)	--	0.00	--	--	0.00	0.00	--	--	--	0.00	--	0.00
Regional Ponds (acres)	--	0.00	0.68	1.68	2.52	--	--	--	--	--	--	--

Table 8-3. BMP composition of selected solution #2

BMP	Subwatershed											
	1	2	3	4	5	6	7	8	9	10	11	12
150 ft ² Rain Garden (unit)	3	0	5	--	--	8	0	36	0	0	40	14
55 Gallon Rain Barrel (unit)	3	0	18	--	--	0	0	74	0	0	83	0
Bioretention (acres)	--	0.00	0.00	--	0.35	1.14	--	--	--	0.00	--	0.00
Porous Pavement (acres)	0.00	0.00	0.13	--	0.15	1.66	3.04	1.71	2.15	2.01	3.83	0.00
Green Roofs (acres)	--	0.00	--	--	0.00	0.00	--	--	--	0.00	--	0.00
Regional Ponds (acres)	--	0.00	1.37	1.68	3.78	--	--	--	--	--	--	--

8.1.2 Peak Flow Reduction Effectiveness at Up-Stream Assessment Points

As described previously the optimization objective was to reduce the peak flow at the most downstream assessment point (AP3). Considering the upstream assessment points (AP1 and AP2) are also hot spot areas where flooding is a concern, the peak flow reduction effectiveness of the two selected solutions at AP1 and AP2 are evaluated.

The results are presented in Figure 8-7 and Figure 8-8 for solutions #1 and #2, respectively. The peak flow reductions for four design storms are compared at AP2 and AP3 for both solutions. The peak flow reductions at AP1 are significantly lower than the other two assessment points for solution #1. This is in part because AP1 is located far from both AP2 and AP3. Since the cost-effective solutions are selected solely based on their peak flow reduction performance at AP3, the same solution may not be optimal for peak reduction at AP1. In addition, for the upper watershed, the majority of peak flow reduction is due to regional ponding downstream from AP1. In this part of the watershed, regional ponds are determined to be much more effective than distributed BMPs for small storm events.

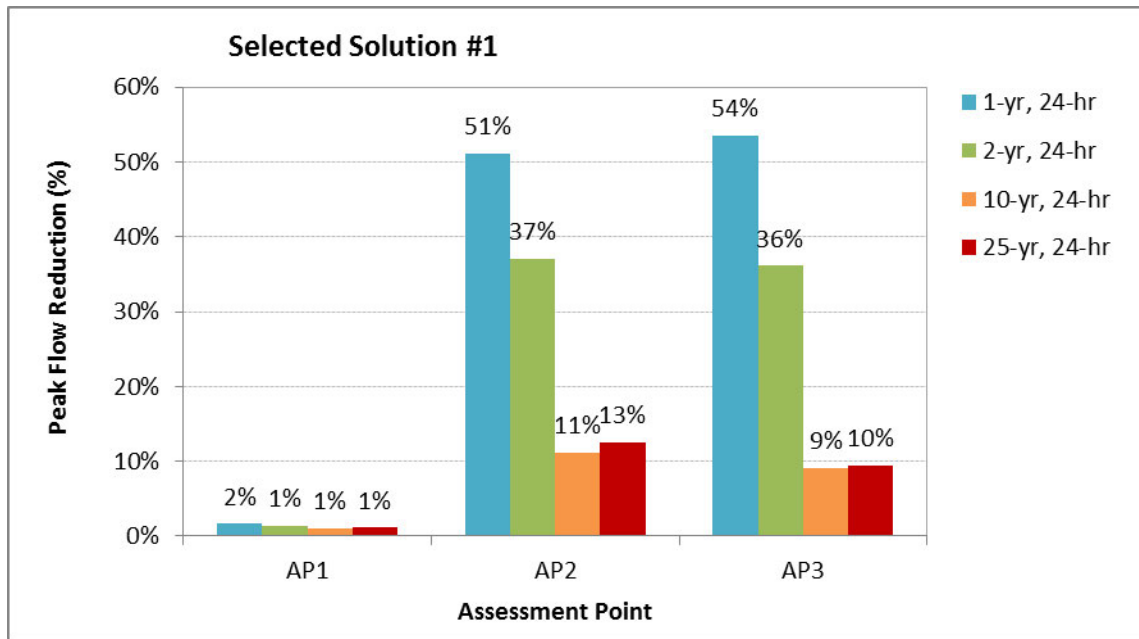


Figure 8-7. Peak flow reduction at three assessment points (solution #1).

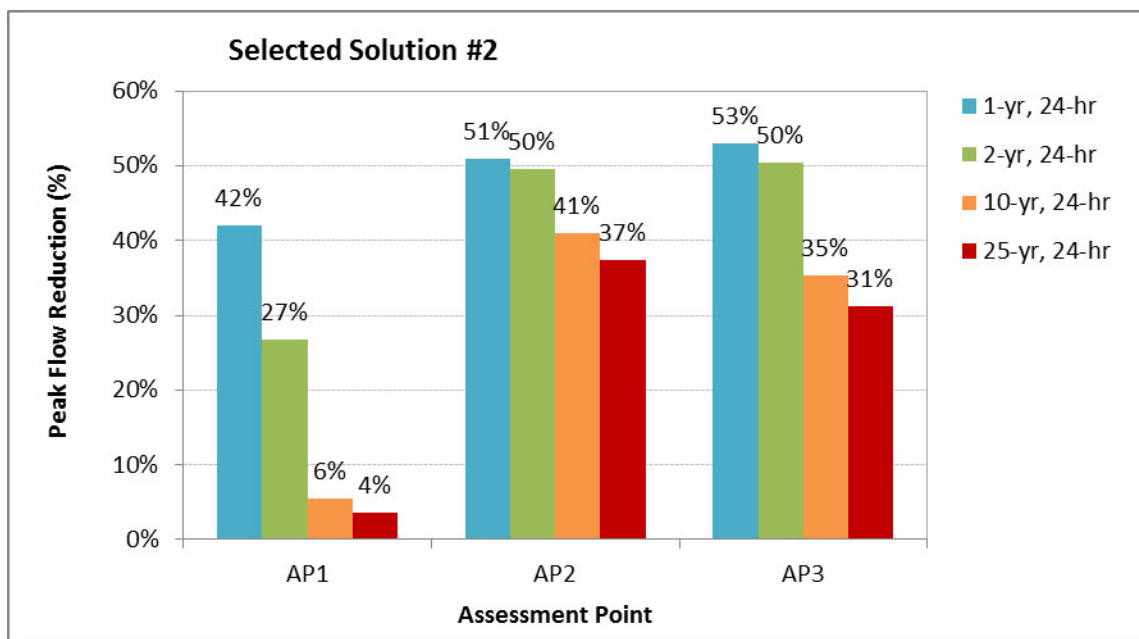


Figure 8-8. Peak flow reduction at three assessment points (solution #2).

9. Summary and Recommendations

Within the Glen Flora pilot area, various BMPs were considered to reduce runoff peak flows. It is important to note that since this *SUSTAIN* project was optimized for peak flow reduction, BMPs provided peak flow reductions were preferentially selected over those that might have provided better pollutant reduction and/or volume control benefits. Below is a summary of lessons learned and recommendations from this case study:

- For each design storm, there was a clear “knee” of the cost-effectiveness curve, above which marginal costs (cost per unit benefit) far exceeded projected benefits. As peak flow reductions exceed 53 percent for the 1-year event and 31 percent for the 25-year event, marginal costs increase. These peak flow reduction represent near optimal cost-effectiveness.
- Implementation of BMPs near the knee of the curve might provide the most cost effective management strategy for peak flow reduction and volume control in the pilot area to meet watershed goals.
- For all design storms, the results suggest that the regional pond is the most cost-effective for controlling peak flows; however distributed BMPs (i.e. porous pavement, bioretention) are needed to provide supplemental volume control in order to achieve the highest peak flow reduction goals for larger design storm events.
- Among the distributed BMPs, porous pavement is the most cost-effective for peak flow reduction, followed by rain barrel and rain garden, then bioretention/bioswale.
- Green roofs are the least favorite and are not chosen in either solution. This outcome is largely dictated by the fact that they have a relatively high unit cost and are generally not designed to provide peak flow attenuation.
- When BMPs were optimized to control larger design storms they were also performed very well for treating smaller storms; however, when BMPs were optimized to treat smaller storms, they were not as effective at controlling larger storms, even though costs were considerably lower.
- Regional ponds have been proposed on private or semi-private land. Landowner willingness will drive the success of regional BMP implementation. The modeled efficiency of those practices suggests that a focused effort on stormwater education and public acceptance from nearby property owners may be worthwhile.
- Coordination with public works projects and street departments will be critical to advancing the use of porous pavement within the watershed. Maintenance costs are included in the lifecycle costs used to derive the cost-effectiveness curve.
- Among distributed BMPs, rain barrels were also among the most cost effective for peak flow control because of the supplemental volume storage they provide (when properly emptied and maintained). A program which promotes or incentivizes rain barrel and rain garden installations by homeowners may be cost-effective from a planning perspective, since some of the purchase cost and all of the maintenance responsibility would be passed on to the homeowner.

With any modeling results, it is important to note the limitations of the models and importance of assumptions made throughout the modeling process. An important assumption to note is the location of the assessment point where optimization is occurring. If this location was changed to further upstream in the watershed, the recommended suite of BMPs and associated costs would change. Requiring higher peak flow control at multiple intermediate points upstream in the watershed may shift more responsibility to distributed BMPs. In addition, as new data are collected on BMPs and their applicability, assumptions should be evaluated and modified as necessary.

10. References

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Appendix A – Peak Flow Hydrographs

